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United States
Department
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Forest Service

Intermountain
Research Station

General Technical
Report INT-GTR-349

May 1997



Using Lightning Location in the Wildland Fire Assessment System

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The Authors

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Robert Burgan received his bachelor's degree in forest engineering in 1963 and his master's degree in forest fire control in 1966 from the University of Montana. From 1963 to 1969, he served on the timber management staff of the Union and Bear-Sleds Districts, Wallowa-Whitman National Forest. From 1969 to 1975, he was a Research Forester on the staff of the Institute of Pacific Islands Forestry, Honolulu, HI. From 1975 to 1987, he was at the Intermountain Fires Sciences Laboratory, Missoula, MT, first as a member of the National Fire-Danger Rating Research Work Unit, and then as a Research Forester in the Fire Behavior Research Work Unit. From 1987 to 1989 he was in Macon, GA, at the Forest Meteorology and Eastern Fire Management Research Work Unit, a part of the Southeastern Forest Experiment Station. In 1989, he returned to the Fire Behavior Research Work Unit in Missoula.

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Larry Bradshaw has been a meteorologist for the Fire Behavior Research Work Unit since 1992. Prior to that he was with Systems for Environmental Management where he was principal investigator of more than 15 research agreements with the USDA Forest Service. He has specialized in the development and applications of climatology to fire management problems and has authored several nationally available computer programs in the field. His current work focus is the continued development and implementation of higher resolution meteorology products in the Wildland Fire Assessment System.

Research Summary

Location of the ground position of lightning discharges has been possible for several years. A technique for using ignition probability calculations together with lightning location data results in maps that are useful to fire managers in making decisions on timescales from historical to real-time. These maps, part of the Wildland Fire Assessment System, will aid fire managers in assessing the potential that lightning will result in reportable fires. The maps are generated using ignition probability based on duff depth, fuel moisture, and fuel type. To match fire potential classes, ignition probabilities are classified into ignition potential classes of low, medium, high, very high, and extreme. Possible benefits are savings in time, fire suppression costs, and perhaps even lives.

Acknowledgments

We thank the members of the ad-hoc lightning location task force for their time, and the Northern Region, especially Walter Tomascak and Charles Rogers, for buying lightning location data for our use. Our special thanks to Howard Roose of the Lolo National Forest for helping us Get Going.

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Introduction

Understanding how lightning turns into wildland fire can lead to saving time, fire suppression costs, and perhaps even lives. A product to help gain that understanding, the Wildland Fire Assessment System (WFAS) (Bradshaw and Burgan 1996), is an integrated fire danger and fire behavior system. Phase 1 of that system, WFAS-MAPS, includes two new maps: lightning strike locations superimposed on lightning ignition potential and fire danger.

Lightning location—determining the place lightning flashes hit the ground—has been generally available in the Western United States since the early 1980's. Used by the Bureau of Land Management in the Initial Attack Management System (IAMS), lightning location data have also been used by other agencies on a sporadic basis, but have not been a part of their formal operational systems for fire danger rating. Present use by the Weather Service is limited to determining when thunderstorms start and where they are.

The lightning ignition potential and lightning on fire danger maps are designed to eventually replace three elements of the present National Fire Danger Rating System (NFDRS) (Deeming and others 1977): Lightning Risk, Lightning Activity Level (LAL), and the Lightning Occurrence Index (LOI). These elements of the present NFDRS are little used, except to note the possibility of high cloud base dry thunderstorm days (LAL 6). There is no place for real-time or archival use of lightning location in the present NFDRS, because it was designed before practical lightning location techniques were fully ready to use.

Application of lightning location to fire dispatch was tried in 1983 (Latham 1983) using then-available ignition probability calculations (Fuquay and others 1979). Crude maps, designed to be used with page-size overlays to estimate probable fire occurrence, were made available by modem (300 baud!). Lightning data were obtained with a research-operated two-station LLP (Lightning Location and Protection, Inc.) array.

The application worked but was not successful. Constant monitoring of three linked small computers was necessary, and data other than lightning locations had to be entered by hand. Maintenance of the remote location station was difficult; in fact, the cables were once cut, raked, and baled.

Both generation and use of the lightning ignition probability information were too difficult to be practical, and the application was shelved while ignition probability calculations, data gathering, and transmission capabilities improved. These needed improvements for lightning location use are now here.

The current data environment is far easier to work with. Fuel moisture data are gathered automatically from the Forest Service's Weather Information Management System (WIMS). Weather Service atmospheric sounding information is available from many sources. Reliable lightning locations are available from the Bureau of Land Management network and from Global Atmospheric, Inc. (a private company that sells lightning location data), and we now have lightning ignition probability algorithms (Latham and Schlieter 1989).

Use of Lightning Location Data

Lightning location data displayed by themselves on a simple map are beneficial to positioning firefighting resources and for requesting additional resources with a small, but potentially significant, lead time. Additional uses have been determined by personnel from the Forest Service, Bureau of Land Management, and Weather Service, as seen in table 1, which combines lightning location data with other information. The existing National Fire Danger Rating System (NFDRS) (Deeming and others 1977), for example, allows rough estimation of fuel state and type over wide areas for such activities as prepositioning firefighting resources and scheduling detection flights. With detection flight costs at approximately \$200 per hour, knowing when not to look can be highly cost effective.

Table 1—Uses for lightning location data. D denotes a desired use, P a present use, — does not apply.

Use	Timeframe		
	Real time	Short (2-24 h)	Historical (>24 h)
Safety	D	D	—
Prescribed natural fire decision	D	—	—
Prepositioning	P	P	D
Detection flights	P	P	—
Holdover estimation	—	D	D
Cause determination	P	D	D
Scenario generation	D	D	D
Contingency manning	P	—	D
Ecosystem management	—	—	P
NFMAS planning	—	—	D

To carry out the activities listed in table 1, and to provide forecasting for lightning-specific events such as fires, value must be added to the lightning location data and presented to users in an easily comprehended, task-specific format. Knowledge of the lightning fire ignition process is used to add this value.

How Lightning Fires Happen

Figure 1 shows the sequence of events leading to a lightning-caused wildfire (Latham 1979). Ignition is caused by lightning strokes with a continuing current (Fuquay and others 1972). The lightning discharge must terminate in a receptive fuel—that is, a fine dead fuel such as dry grass, punky wood, tree litter, duff, or the rotted center of a standing snag. The fuel must be dry enough or packed enough to ignite. Some fuels, such as duff, ignite by lightning even though they are not in the “1-hour” fuel moisture category. Some fuels, such as peat, ignite even though they may be very wet.

After ignition, three things could happen. First, the fire could go out. This will happen if the fuel conditions cannot maintain the fire from a propagation standpoint, even if an ignition is possible. Second, the fire could spread for some time, until either rain or burning into an unsuitable fuel extinguishes it. Third, the fire could continue to grow until it becomes large enough to be seen. It then becomes a reportable fire.

The part of figure 1 between the cloud-ground lightning and the reportable fire is not amenable to field study except after the fact. Statistics can, of course, be established for the connection between lightning flashes and fire. These statistics must be conditioned on the fuel type, the present and immediate future of the moisture content of the fuels (rainfall), and the

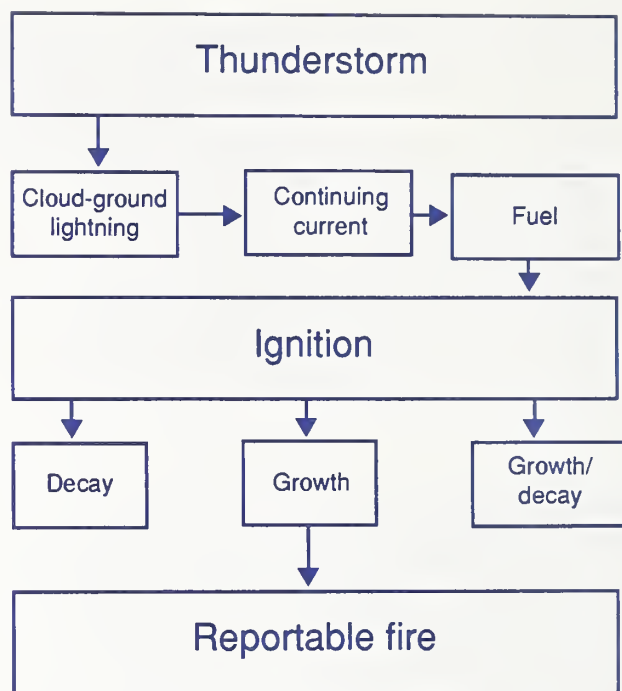


Figure 1—The lightning-caused fire process.

characteristics of the continuing current. The relationships necessary were developed by Latham and Schlieter (1989) based on laboratory studies of arc ignition of actual fuels.

The ignition studies yielded some surprising results for lightning ignition. First, only the duration of the continuing current (CC) has an effect on the ignition probability. The current flow in the CC is not significant in the ignition process. Simply put, the CC arc gasifies the fuels through which it passes, generating (mostly) carbon dioxide. Heat passes to the fuel outside the boundary of the discharge by radiation and convection, with convective heating predominant. What is left is a cylinder of glowing and flaming combustion that may or may not spread to become a fire. The cylinder is about 1 to 2 cm in diameter. Because of the destruction of fuel in the core of the discharge, and because the temperature structure of the arc does not depend on the current (Latham 1986), the duration of the discharge determines the energy transferred to the fuel. This relationship between duration of discharge and ignition was found for all fuels tested. In addition, there was no difference in ignition probabilities between negative and positive laboratory arcs.

The second surprise result from the ignition experiments was that for some fuels, moisture content is not significant for ignition. Duff from evergreen species with short to medium needles, such as Douglas-fir and

lodgepole pine, ignites as a function of the depth of the duff layer and duration of discharge, with moisture playing a negligible role, at least up to 40 percent of dry weight. Ignition probability for forests composed predominantly of these species can be set in advance of the fire season. Growth to a reportable fire, and the progress of glowing combustion leading to long time delay (holdover) fires, are, however, subject to moisture constraints. This may also be true of the rotten hearts of standing snags. Work remains to be done to prove this.

Laboratory tests, then, give the probability of ignition as a function of a lightning characteristic, fuel state, duff depth, or combination. Lightning location data do not currently have continuing current duration as an output characteristic. There are, however, some measurements of CC characteristics that can help surmount this difficulty. The CC components of lightning strokes in Northern Rocky Mountain thunderstorms have duration distributions, for both positive and negative strokes, that are well fit by a Weibull distribution. Since a distribution function is known, the marginal distribution of ignition probability per CC occurrence can be calculated (Latham and Schlieter 1989). An example is given in figure 2. Marginal probabilities for positive and negative strokes differ because the duration statistics of the two differ. Not every flash, either positive or negative, has a CC. In the Northern Rocky Mountains, where the data were taken, 20 percent of the negative flashes to ground and 97 percent of the positive flashes contained CC's. With this information, a probability of ignition for each flash in the lightning location data can be determined if the fuel state is known.

Fuel Type and Moisture

Precise fuel type and moisture are not realistically available for the terminus of lightning discharges that strike in the forest. Rocks and bare patches, rotten logs and "atypical" fuels in every patch of forest preclude that possibility. So every flash probably cannot be assigned a probability. There is, however, a fuel type map that has resolution matching lightning location accuracies quite well. The fuel map was derived from a national land cover characteristics map produced by the Earth Resources (EROS) Data Center (Loveland and others 1991). Because the classification is well defined, the fuel type map can be used for ignition probability estimation, including duff depth (Brown and See 1981). Fuel moisture is also available from WIMS. Because the moisture timelag for the fuels that ignite by lightning is on the order of 20 to 100 hours (Latham and Schlieter 1989), a lightning ignition probability map can be formed that will be useable for at least 1 day.

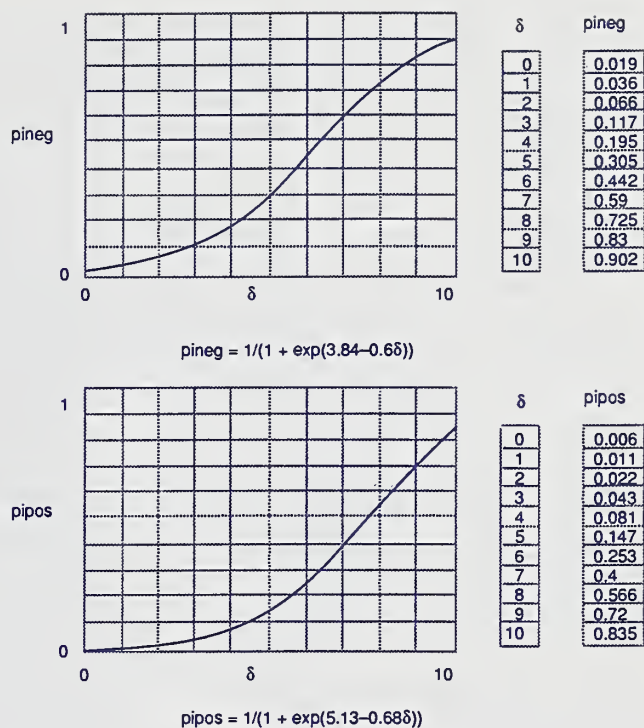


Figure 2—Examples of ignition probability curves (after Latham and Schlieter 1989; fig. 7). These are the marginal ignition probabilities for lodgepole pine duff. The top curve shows the probability of negative discharges; the bottom curve, positive discharges.

Additional data are required to estimate fuel moisture effects. Rain that accompanies most thunderstorms can act to reduce the probability that a lightning-ignited fire will sustain to reportability. This effect was accounted for in an early ignition predictor (Fuquay and others 1979; Latham 1983). Although the ignition probability estimated by this model was not good, the rain effects were accounted for and could be used in newer systems until radar rainfall estimates are readily available. The present lightning ignition maps do not include rainfall effects.

We should note a limitation of the lightning location system. We have not accounted for the patchiness of fuels in the probability of ignition. We assumed a homogeneous fuel within each square kilometer. A uniform duff depth (25 cm maximum) was chosen for each square kilometer of short-needled species, whereas in reality duff depth is variable. Fuel moistures are limited to 40 percent of dry weight as a maximum. Combining negative and positive flash probabilities assumes that the statistics for the relative numbers of flashes is well known. Finally, the breakpoints for

high, extreme, and so forth, are assumed at this time. While these shortcomings are not trivial, we have dealt with them appropriately. Ongoing research and feedback from users will further the product's utility and accuracy.

Application

A lightning ignition potential map is generated for an area according to the flow diagram of figure 3. In this diagram, the marginal ignition probability is used in "ignition probability per cloud to ground (cg) flash."

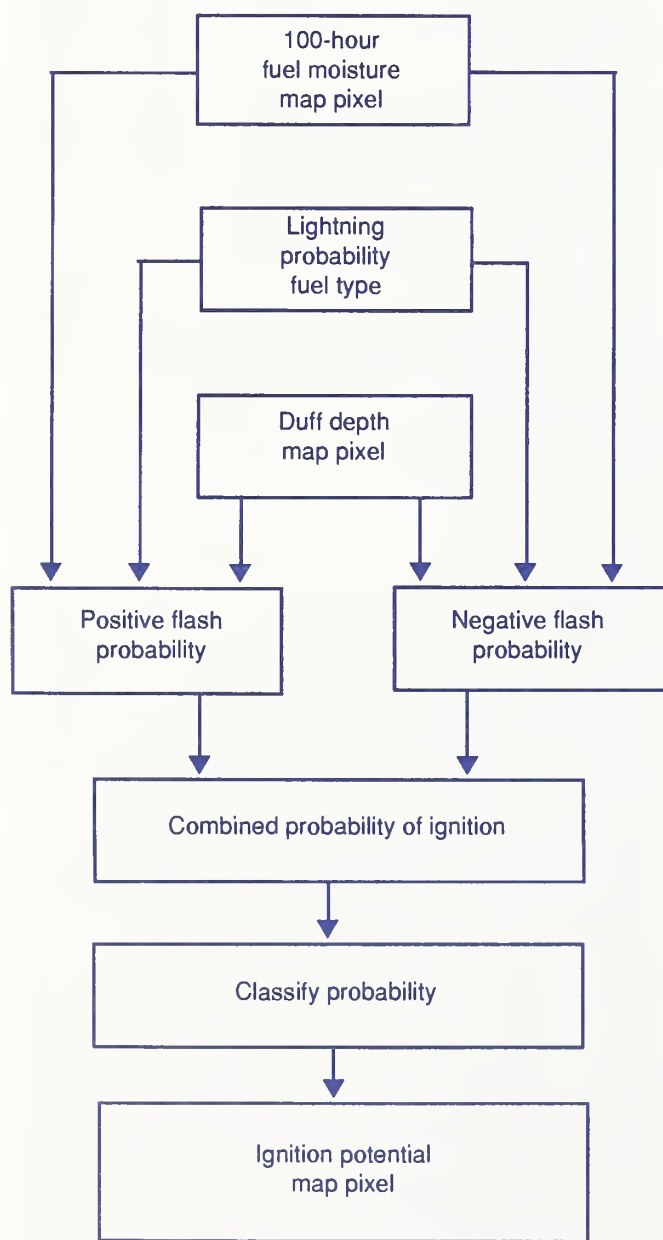


Figure 3—The ignition potential map generation process.

Because we will produce only one probability map, not separate maps for positive and negative flashes, the probabilities for positive and negative flashes are combined into an ignition probability per flash.

Ignition potential maps are generated according to the physical process as outlined in the previous section, "How Lightning Fires Happen." The potential map is independent of whether or not lightning is present; it shows the probability of ignition if lightning does happen. To produce the map, we need the NFDRS 100-hour fuel moisture, the fuel type, and the duff depth (the duff depth is inferred by fuel type). These data need to be spatially connected. For now, interpolated fuel moisture data are used, along with a specialized ignition fuel map. Because we cannot assign a probability of ignition to each flash, we are superimposing lightning location data on the ignition potential map as an experimental product to be available in the near future.

Data will be ingested at the National Interagency Fire Center, and an ignition potential map generated daily. Lightning data will be superimposed on several ignition potential and fire potential maps at various scales of space and time. A successful prototype of this display was carried out during 1996. The maps are available on the Forest Service home page (<http://nww.fs.fed.us/land/wfas/>) (Caring for the Land, WFAS-MAPS). The GIF maps of 1-hour and 3-hour lightning location summaries superimposed on lightning ignition potential and fire danger are supplied each hour to the Northern Region of the USDA Forest Service (western Montana, Idaho, and parts of Wyoming and North Dakota). The GIF viewers can be used to display these maps (fig. 4).

Ignition potential maps are one component of a suite of maps and other fire management tools. The NFDRS tools such as Energy Release Component or Burning Index should be used to help assess the consequences of an ignition. Local rainfall data, if available, can aid in determining the possibility that an ignition will not propagate, or if it does, will go out. For example, a fire that started in duff or litter near a tree will reach the dripline and may not survive.

Values at risk can be used with daily fire potential to plan staffing or to find potential understaffed areas. Forecast thunderstorm activity can also be applied.

A pilot program to begin implementation of value-added knowledge to lightning location is under way in a cooperative effort with the Northern Region of the Forest Service. Experience with the pilot Wildland Fire Assessment System and the lightning location component will lead to improvements in this wildland fire prediction and firefighting tool. We are presently studying the question of survivability of ignitions.



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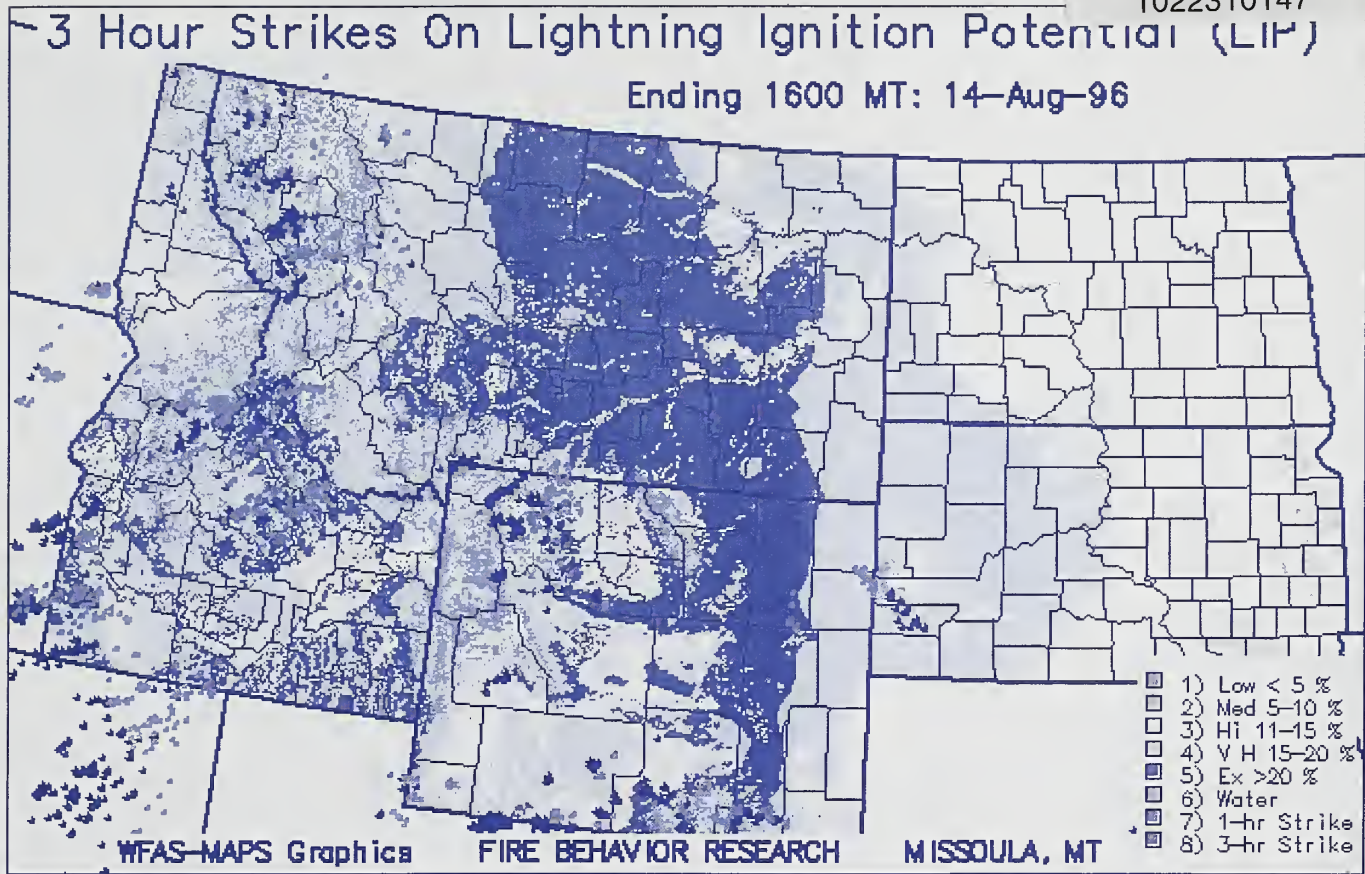


Figure 4—An ignition potential map with superimposed lightning discharges.

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Lightning location data are superimposed on lightning ignition potential and on fire danger as experimental phase 1 map products of the Wildland Fire Assessment System. As pilot components of this next generation fire danger/fire behavior system, the maps are designed to help fire managers assess the occurrence of lightning and its potential to result in reportable fires. Possible benefits are savings in time, fire suppression costs, and perhaps even lives.

Keywords: fire probability, fuel moisture, lightning fires, WFAS, fire potential, fire danger



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